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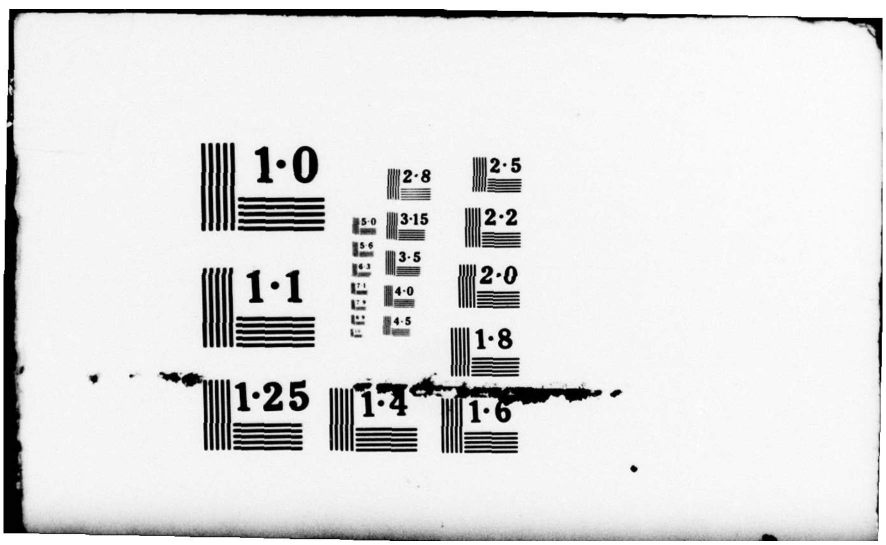
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NONLINEAR VIBRATIONS OF A MILDLY SLOPING PANEL UNDER THE EFFECT OF WIND GUSTS

by

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EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

NONLINEAR VIBRATIONS OF A MILDLY SLOPING PANEL UNDER THE EFFECT OF WIND GUSTS

A.S. Vol'mir, A.F. Danilenko (Moscow)

The works of S. Crandall and Yu.A. Fedorov and a number of others are devoted to the investigation of small nonlinear random vibrations of plates and shells. In this article an attempt is made to solve a similar problem without limiting the degree of nonlinearity.

Considering vibrations of only the basic tone, for which the effect of nonlinearity is the most significant, we find the mathematical expectation and dispersion of the normal movements of the panel. Let us take, as in [1], the equations of the motion of a panel which is hinged supported on a rib freely shifting in the plan.

Approximating the normal movements by the expression

$$w(x, y, t) = f(t) \sin(\pi x/a) \sin(\pi y/b), \qquad (1)$$

where a and b are the length and width of the panel, from the equation of motion [1] we find the stress function

$$\Phi(x, y, t) = (E/32) f^2(t) [\lambda^2 \cos(2\pi x/a) + \lambda^{-2} \cos(2\pi y/b)] + (E/R\pi^2) a^2 (1 + \lambda^2)^{-2} f(t) \sin(\pi x/a) \sin(\pi y/b) - 0,5\, p\, y^2,$$

and for determining the generalized coordinate f we get the equation

$$\ddot{f} + 2\beta\omega_0 \dot{f} + \omega_0^2 f = Q(t). \qquad (2)$$

Here $\beta = \varepsilon/2\omega_0$; c - the propagation velocity of the longitudinal waves; μ - the coefficient of lateral deformation; the parameter of curvature $k = b^2/Rh$; $\lambda = a/b$; the generalized force

$$Q(t) = \eta f^3(t) + \zeta f^2(t) + \xi q(t); \quad \eta = -c^2\pi^4(1+\lambda^4)/16a^4; \quad \zeta = -2c^2kh\,[1+16/(1+\lambda^2)^2]/3b^4;$$
$$\xi = 16/\pi^2\rho h;$$

the square of the basic frequency of the vibrations, taking the longitudinal compressive load p into account,

$$\omega_0^2 = \left(\frac{c\pi h}{ab}\right)^2\left[\frac{\pi^2(1+\lambda^2)^2}{12\lambda^2(1-\mu^2)} + \frac{k^2\lambda^2}{\pi^2(1+\lambda^2)^2} - \frac{pb^2}{Eh^2}\right].$$

Let us linearize the nonlinear equation (2) similar to [2]:

$$f = rf_0, \qquad (3)$$

where f_0 is the linear solution, r - the constant; then we seek the solution to it in the form [3] of $f(t) = \int_{-\infty}^{t} h(t-\tau)Q(\tau)\,d\tau$, где $h(t-\tau)$ - the impulse transfer function equal to the reaction of the system at the moment of time t for a single impulse at the moment of time τ.

By comparing the integral deflections of the nonlinear (2) and linearized (2)-(3) systems, for determining the constant r we find the equation

$$\int_{-\infty}^{t} h(t-\tau)\left[r^3\eta f_0^3(\tau) + r^2\zeta f_0^2(\tau) + \xi q(\tau)\right]d\tau = rf_0(t). \qquad (4)$$

Since an indirect determination of r from (4) is impossible, by taking the operations of averaging and finding of dispersion, instead of (4) we get

$$1 - r_m + a_1 r_m^2 + a_2 r_m^3 = 0; \quad 1 + (a_3-1)r_D^2 + a_4 r_D^3 + a_5 r_D^4 + a_6 r_D^5 + a_7 r_D^6 = 0, \qquad (5)$$

where

$$a_1 = (\zeta/m_{f_0})\int_{-\infty}^{t} h(t-\tau)M\left[f_0^2(\tau)\right]d\tau; \quad a_2 = (\eta/m_{f_0})\int_{-\infty}^{t} h(t-\tau)M\left[f_0^3(\tau)\right]d\tau$$

(the remaining are determined similarly); M[...] is the operation of averaging;

$$f_0(t) = \xi\int_{-\infty}^{t} h(t-\tau)q(\tau)\,d\tau; \quad m_{f_0} = \xi\int_{-\infty}^{t} h(t-\tau)M[q(\tau)]\,d\tau.$$

By finding the actual roots of (5) and using (1), let us determine the mathematical expectations and dispersions of the normal movements

$$m_w(x, y) = m_f \sin(\pi x/a) \sin(\pi y/b); \quad D_w(x, y) = D_f \sin^2(\pi x/a) \sin^2(\pi y/b),$$

where

$$m_f = r_m m_{f_0}; \quad D_f = r_D^2 D_{f_0}.$$

Let us note that the normalized solution is the first approximation of the modified method [2]; the question of the convergence of the method of successive approximations for the case of periodic vibrations was discussed in work [4].

Example. Let us examine the case of the effect on a panel of a velocity head $q(t) = 0.5 \rho_0 c_0 [m_v + v(t)]^2$, where ρ_0 is the air density; c_0 - aerodynamic coefficient; m_v - average wind speed; v(t) - a stationary Gaussian process with a zero average value and correlation function [5] $K_v(t_1, t_2) = D_v \exp(-m_v|t_2 - t_1|/L)$, where D_v is the dispersion of the wind speed; L - the scale of the turbulence. Let us take L = 600 m; $\lambda = 1$; $\beta = 0.01$; $\mu = 0.32$; k = 12 (rise of the panel is equal 1.5 h); $D_v^{0.5}/m_v = 0.1$; the longitudinal load p corresponds to half of the upper critical stress.

Results of the computations according to equations (3) and (5) for the central point of the panel are given on Figs. 1 and 2, where $q^* = 0.5 \rho_0 c_0 m_v^2 a^4 / E h^4$; $m^* = m_f/h$; $\sigma^* = D_f^{0.5}/h$. The load directed toward the center of curvature of the panel corresponds to positive values of the parameter q*, and the load from the center - to negative values.

As is evident from the graphs, in a certain region of the loads the phenomena of snapping and separation of the vibrations are possible.

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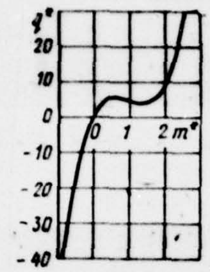

Fig. 1.

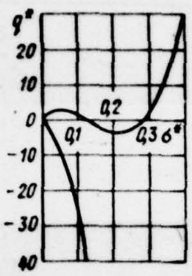

Fig. 2.

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